# Plasma and Electro-energetic Physics

**Date: 05 March 2013**

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***Integrity ★ Service ★ Excellence***

# Report Documentation Page

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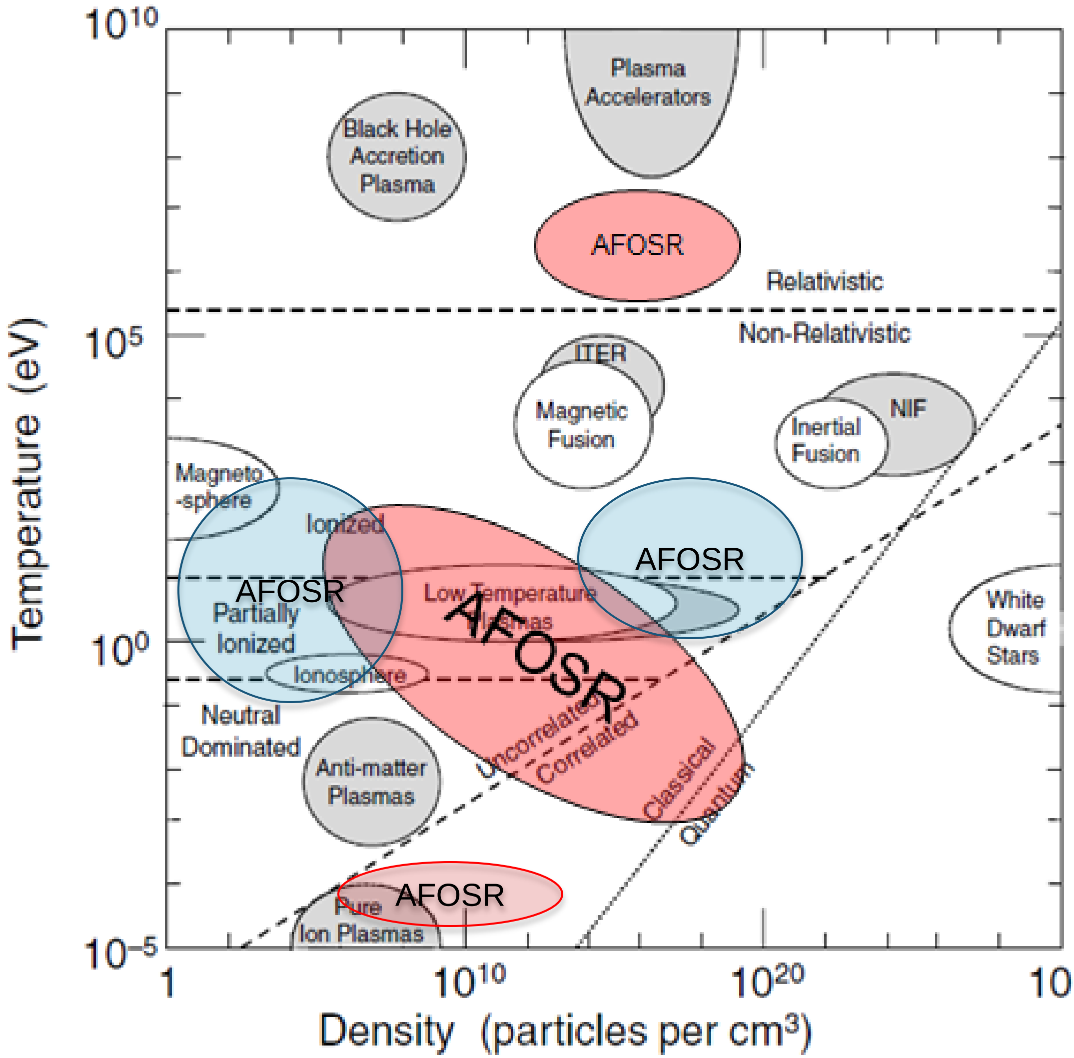
# Plasma and Electro-Energetic Physics

**NAME: John Luginsland ,**
**Plasma and Electro-energetic Physics**

**<u>BRIEF DESCRIPTION OF PORTFOLIO</u>:**
**Explore scientific opportunities in plasmas and electro-energetic physics where *<u>energy-dense objects</u>* powered by electromagnetic energy can provide new vistas in high-power electronics, plasma-enabled chemistry, and fluid/turbulence dynamics arenas**

**<u>Sub-area</u>: High Power Microwave (HPM) sources, non-equilibrium plasmas, and pulsed power**



# "What's past is prologue…"

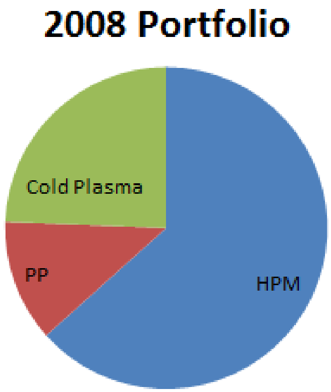
**2008 Spring Review**

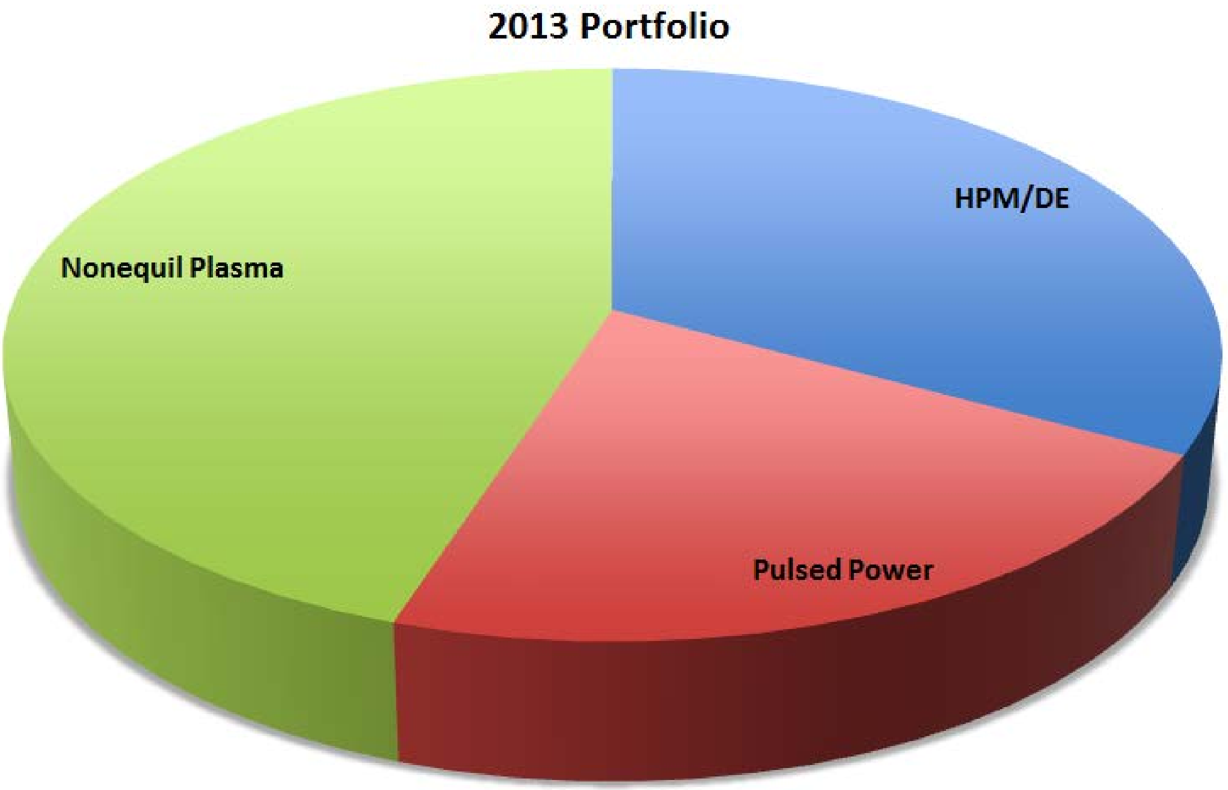
**BRIEF DESCRIPTION OF PORTFOLIO:**

**To advance the state-of-the-art in high power electronics for USAF applications in DEW, radar, EW, and communications.**

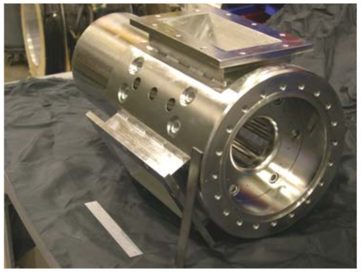
**Sub-area:**

- **HPM sources**
- **Pulsed power**
- **Cold plasma**

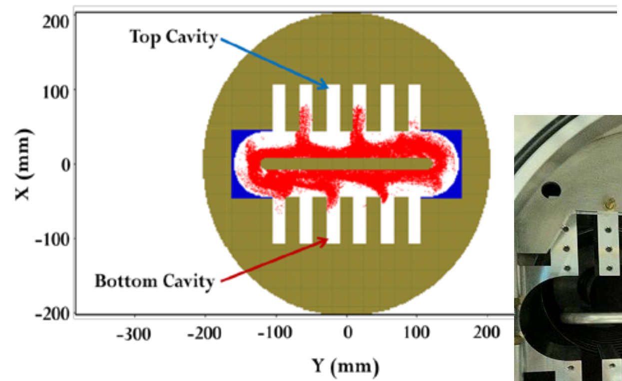


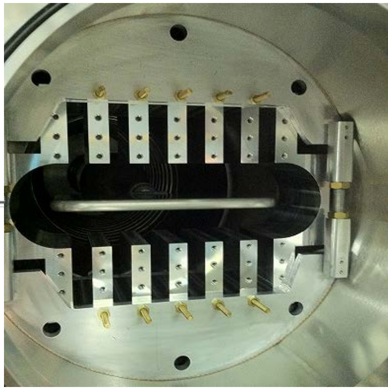
# Plasma and Electro-energetic Physics



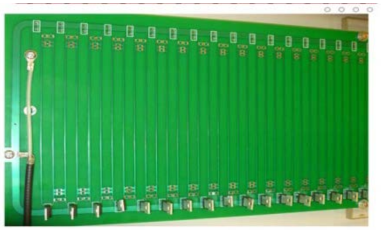
~GW for *short* periods


## HPM/DE

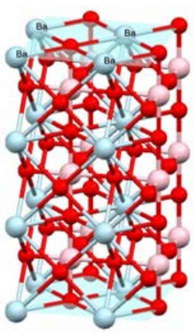


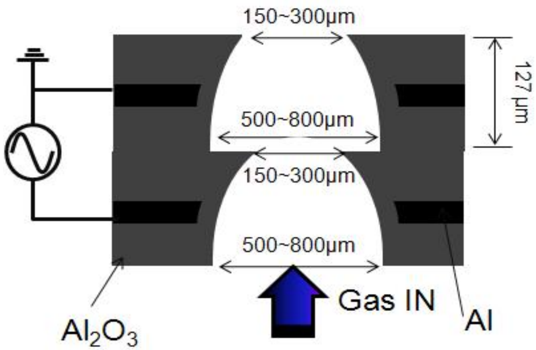
## PP

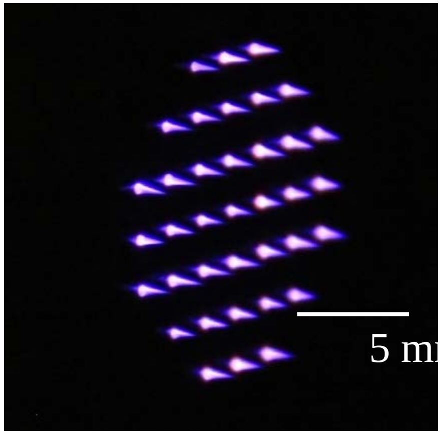


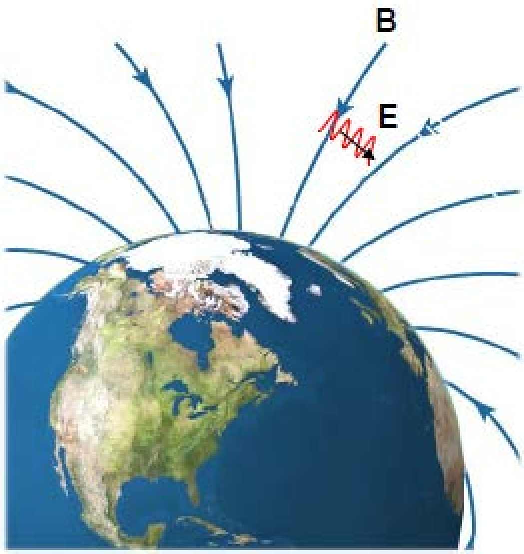
***Often far from equilibrium***

## NEP





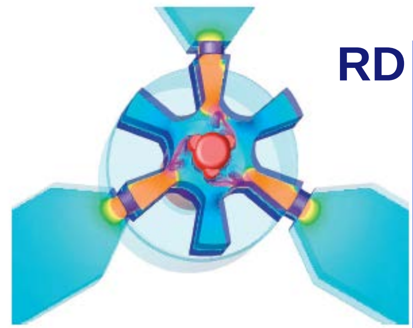



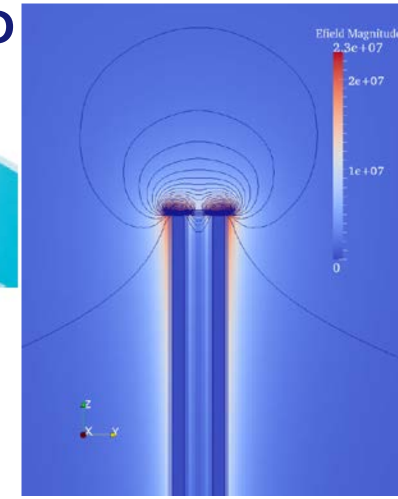



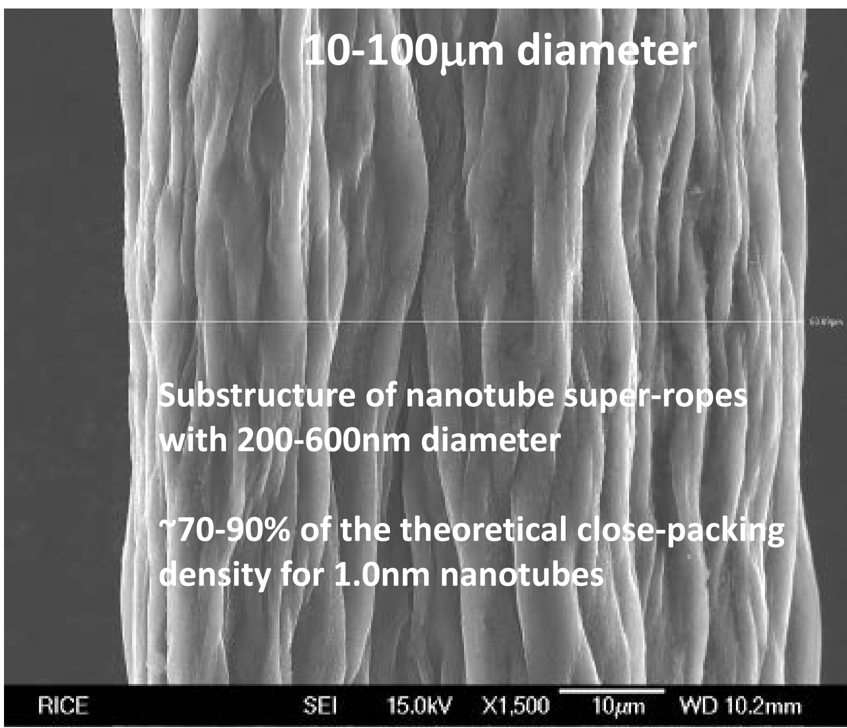
# High Power Microwaves

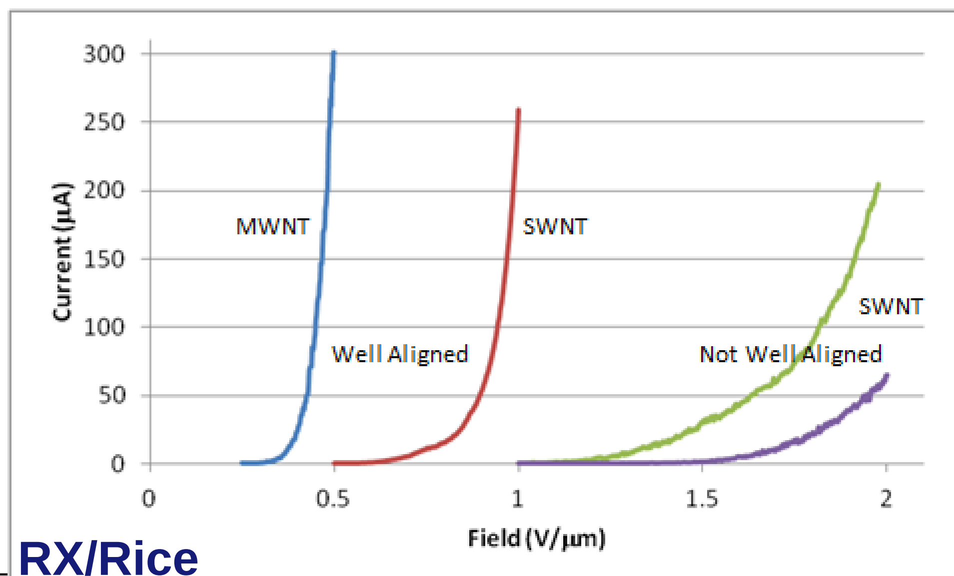
- HPM and vacuum electronics has demonstrated $Pf^2$ (energy density) doubling every 26 month since 1930
  - MW-GW, ~30-40% efficient, 0.1-1 μs
- Emission physics fundamental physics for input power (Joint RD/RX/EOARD/AFOSR)

RD





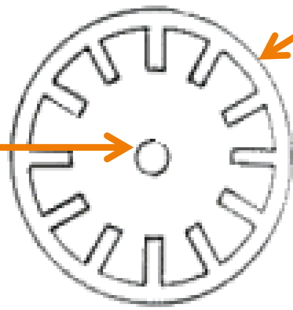




RX/Rice

# Recirculating Magnetron
## (U-Michigan and AFRL/RD)

Anode

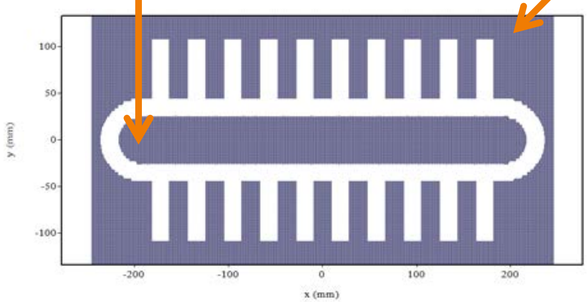
Cathode



**Conventional 12 vane magnetron**

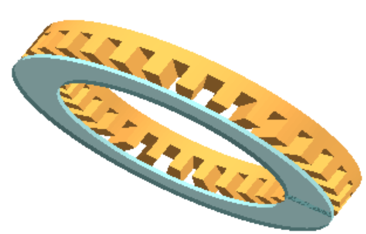
Cathode

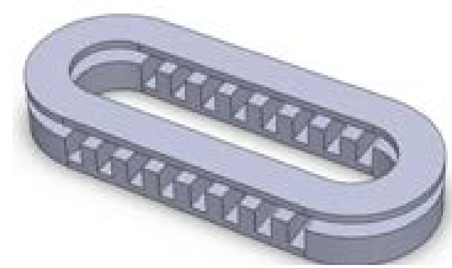
Anode



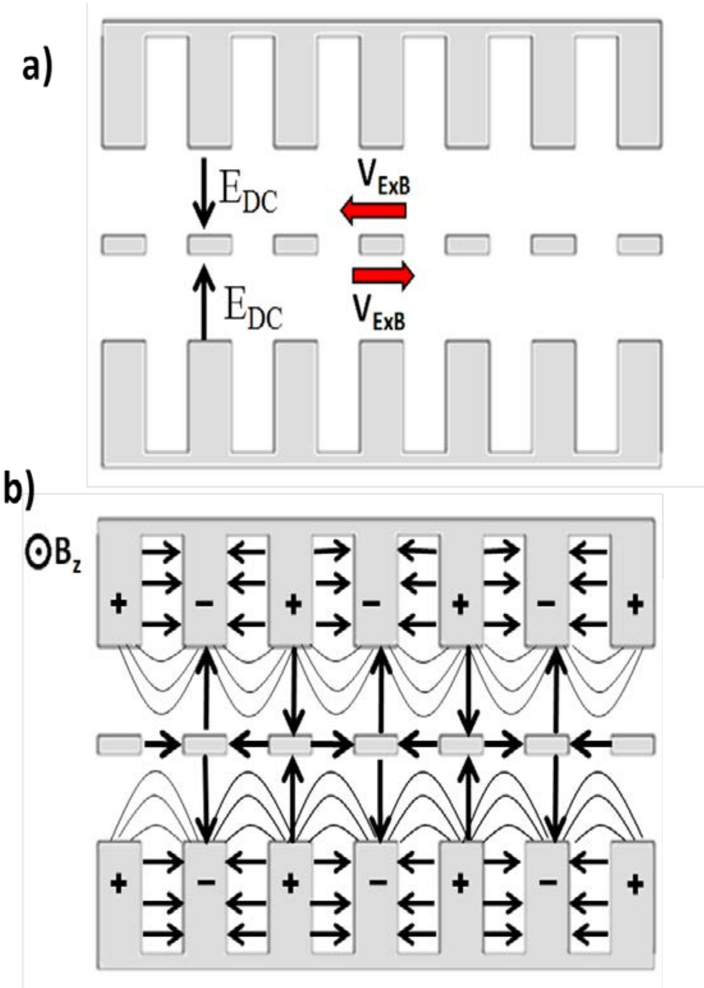

**Conventional-polarity 20-vane RPM**

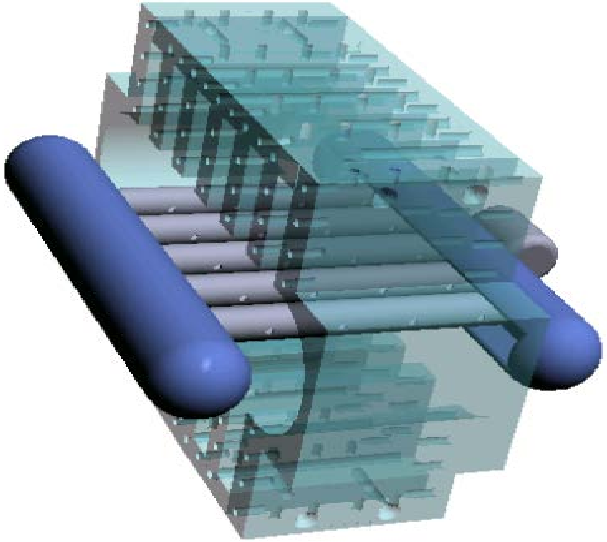
- Larger cathode surface area provides higher current
- Larger anode area allows for faster heat dissipation
- RPM allows for nearly full electron beam recirculation
- Planar cavities are decoupled from the anode-cathode and spacing
- Magnetic field volume (V) scales linearly with # cavities (N) instead of ($N^2$) as with cylindrical magnetron

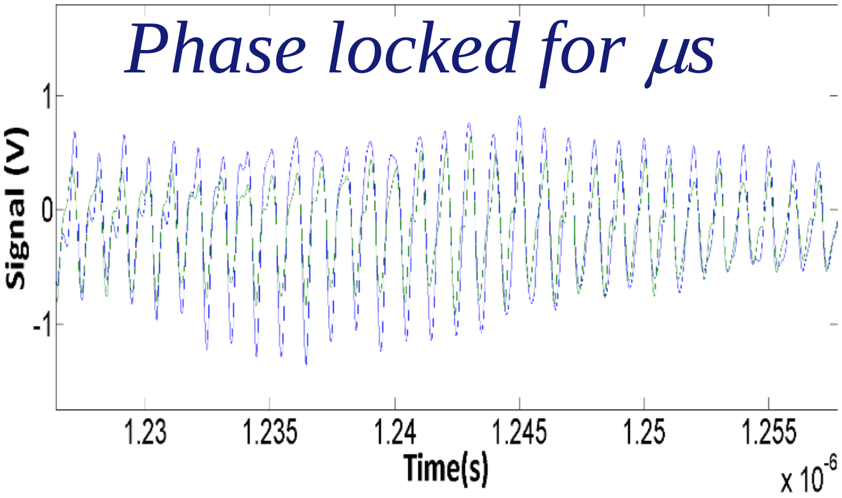




# Phase Control

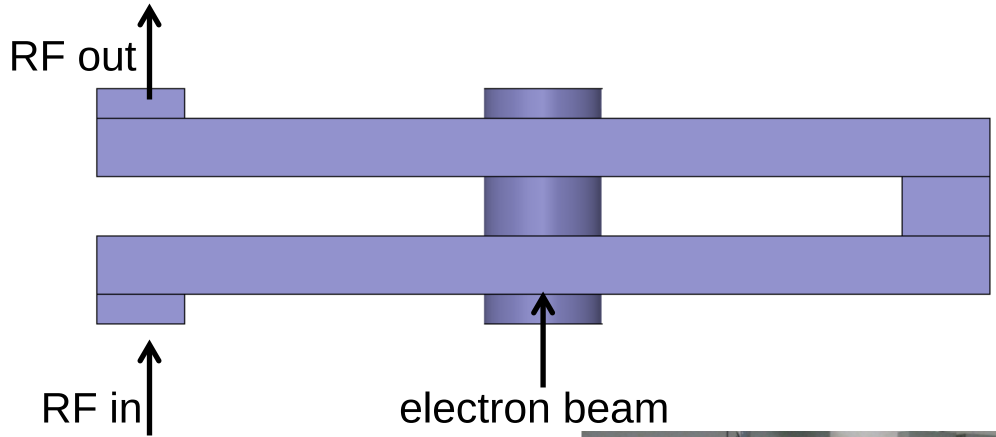


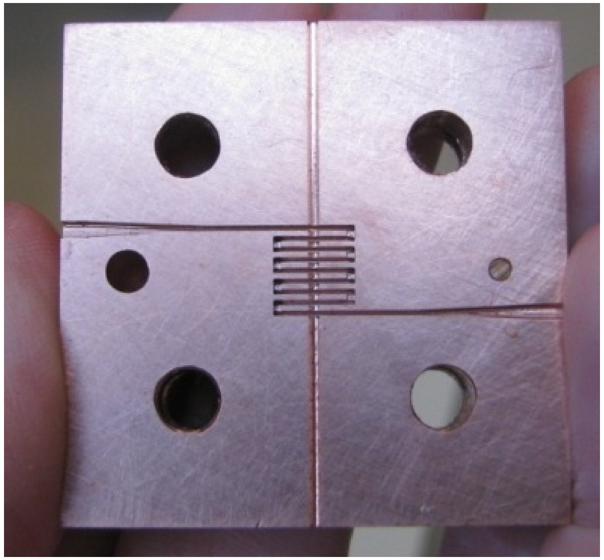



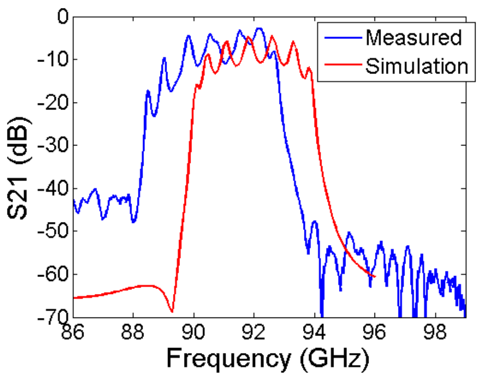


# Amplifiers vs Oscillators
# A Grand Challenge


*Fundamental challenge in mating high power (nonlinearity) and amplification (linearity)*

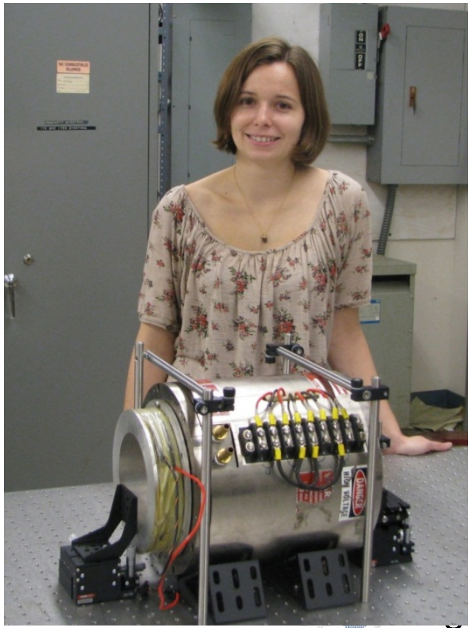


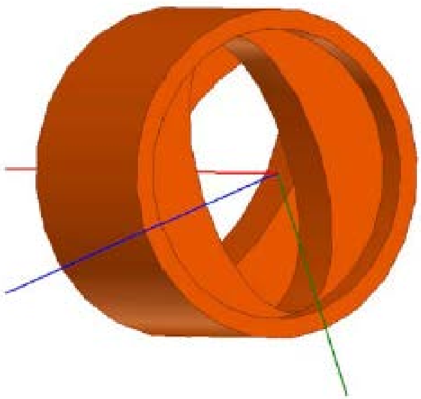


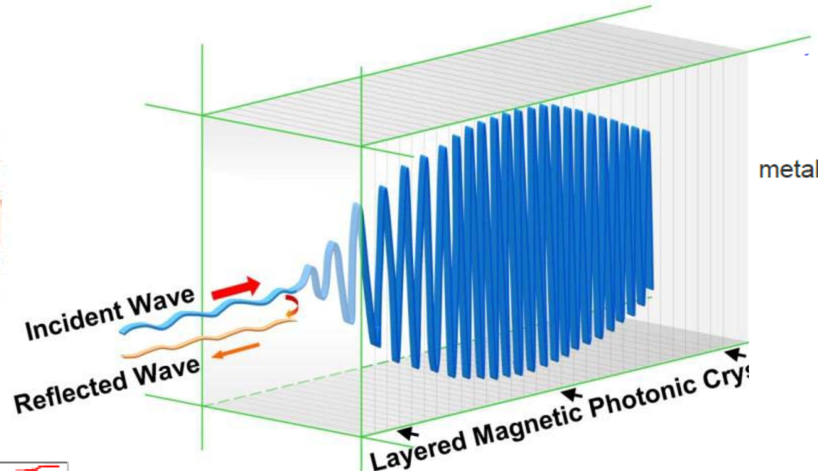

**30dB gain at 300W (200MHz BW)**

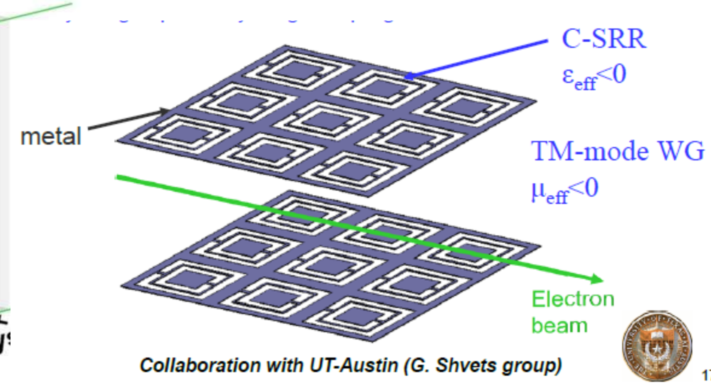
**MIT**

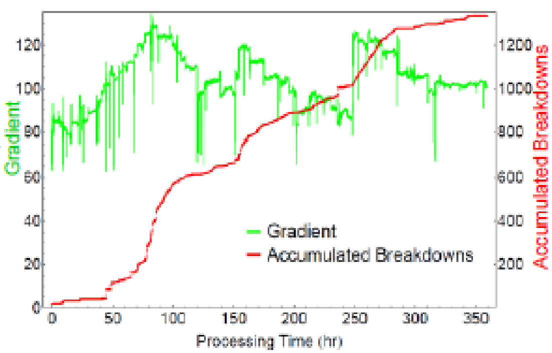


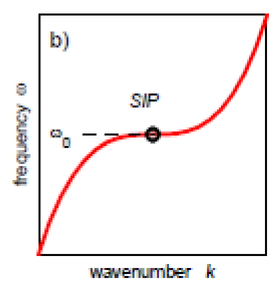
# High Power MM for Transformation Optics

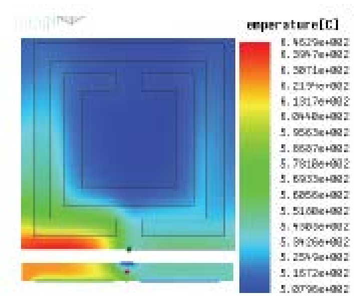


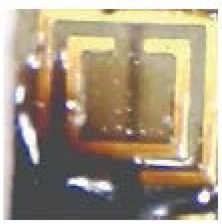


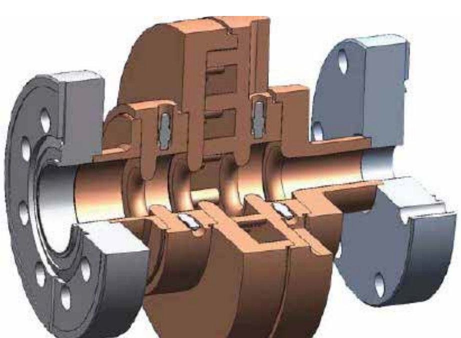







**FY'12 MURI**

**Transformational Electromagnetics**

University of California Irvine — MTMs design

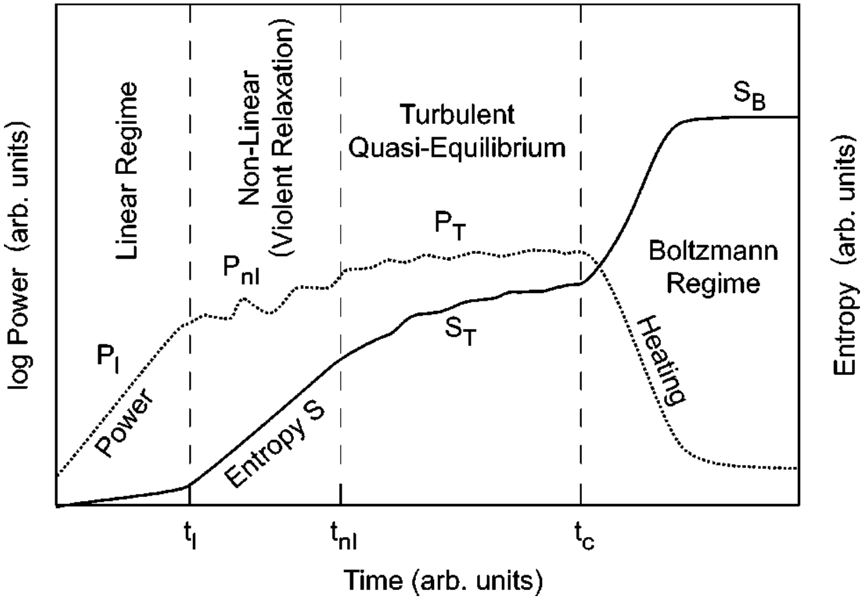
LSU — Louisiana State University

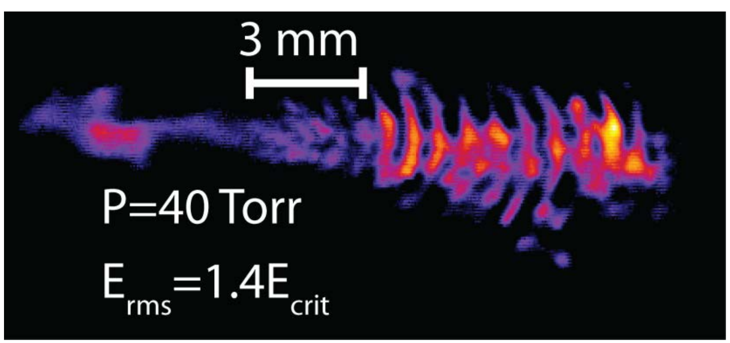
The Ohio State University — MTMs design and characterization, antennas

UNM Electrical & Computer Engineering — High Power VEDs, MTMs, plasma diagnostics

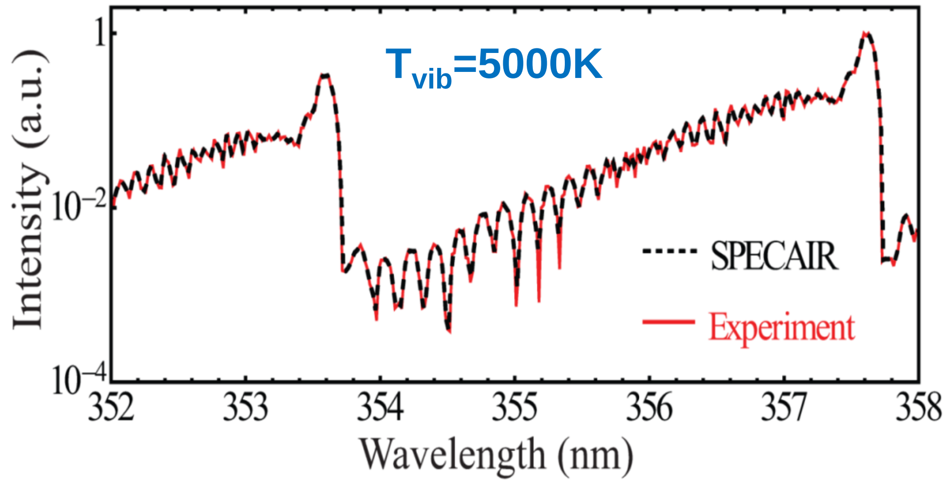
@MIT PSFC — VEDs, MTMs

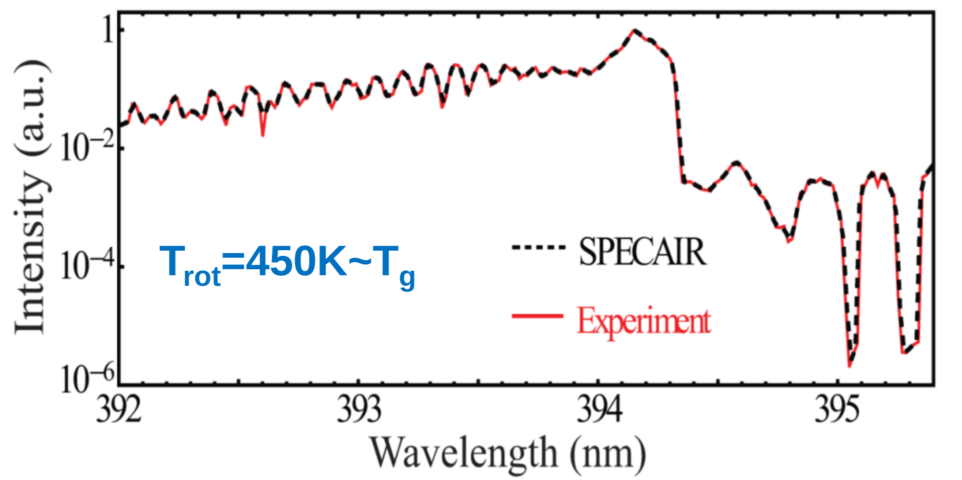
# Non-Equilibrium Air Plasma



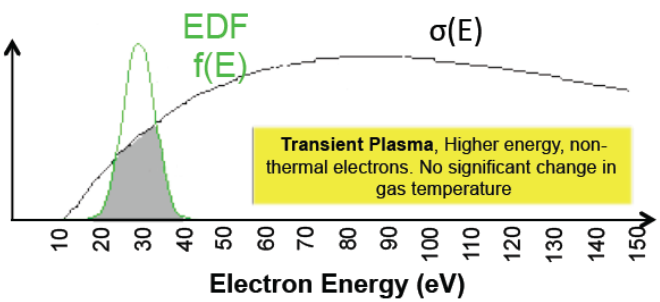

***Light from 3 $\mu$s discharge***

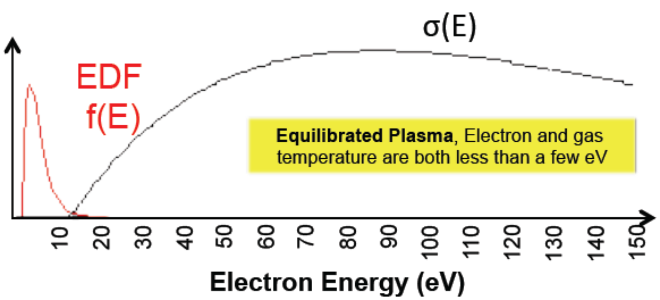


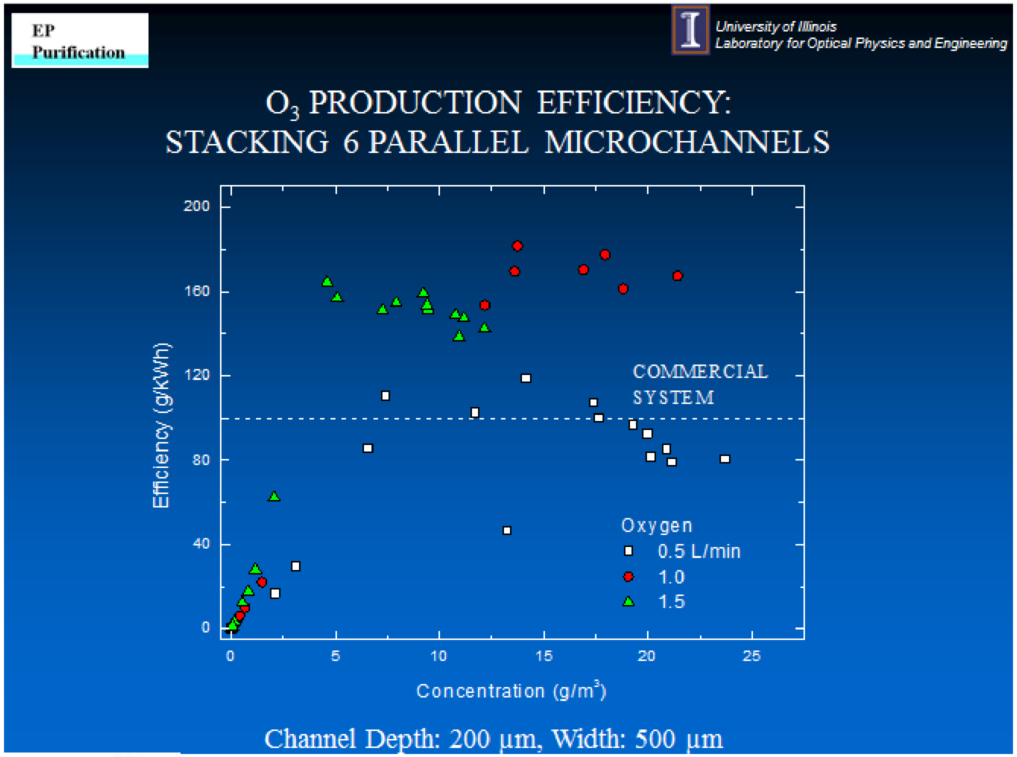



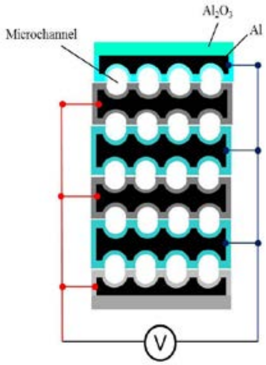

***MIT for CHPM effort/Energy Transfer BRI***

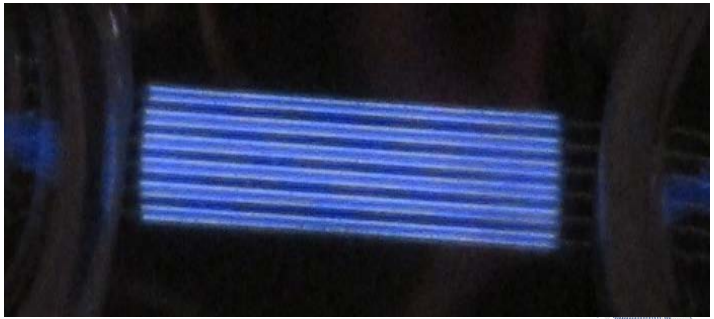
# Novel Plasma Chemistry



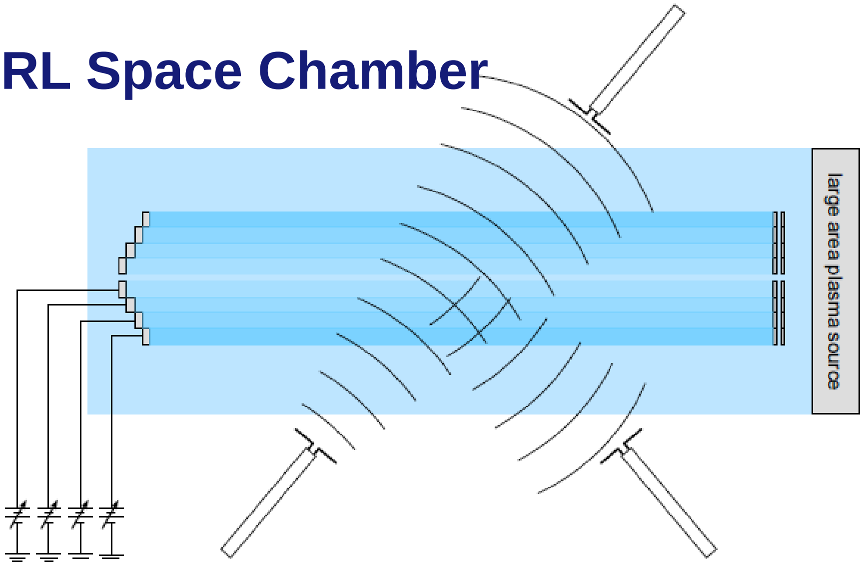



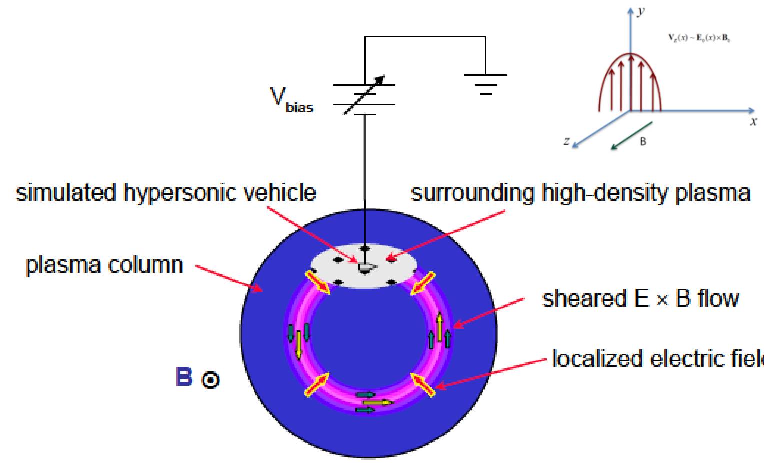



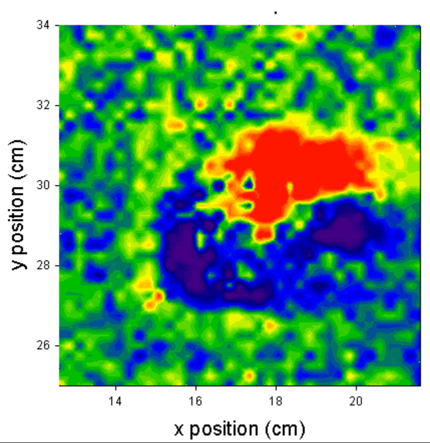



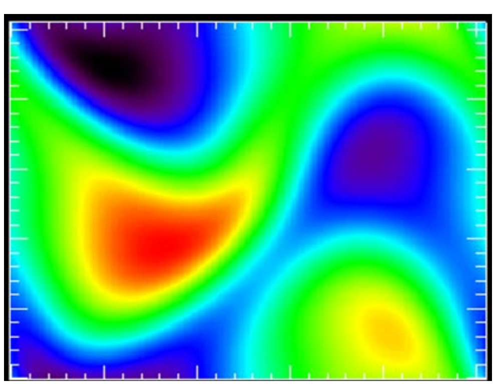
# Non-Equilibrium Plasma in Space

## NRL Space Chamber



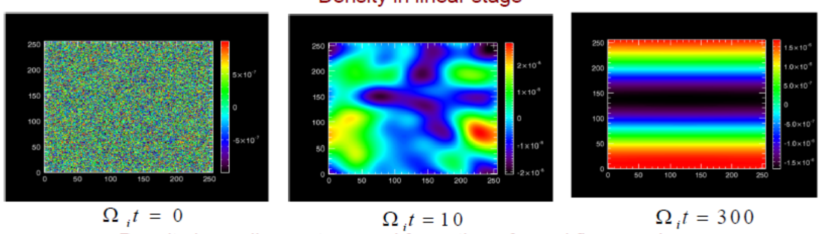



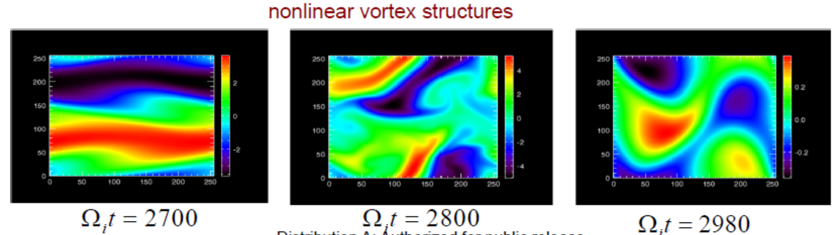



## AFRL/RY Theory on LH and IAW

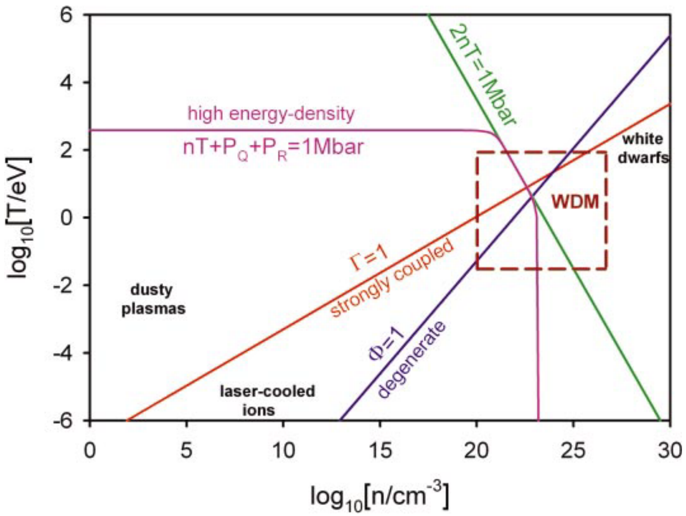
Density in linear stage

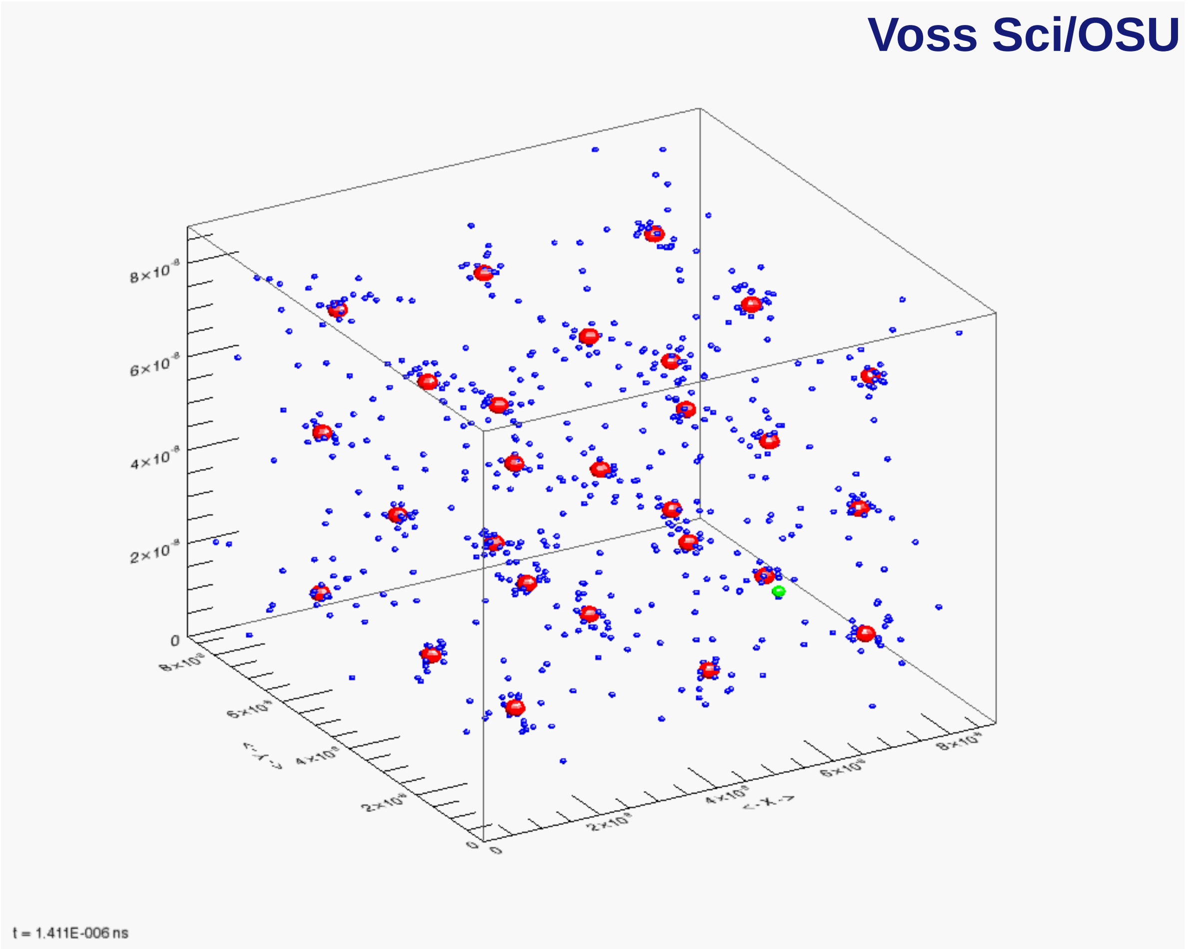



Density in nonlinear stage and formation of zonal flows and nonlinear vortex structures



# Strongly Coupled Plasma
## ($\Gamma$ = 99 = PE/KE)




**Ultracold, neutral plasma**

# Strongly Coupled Plasma

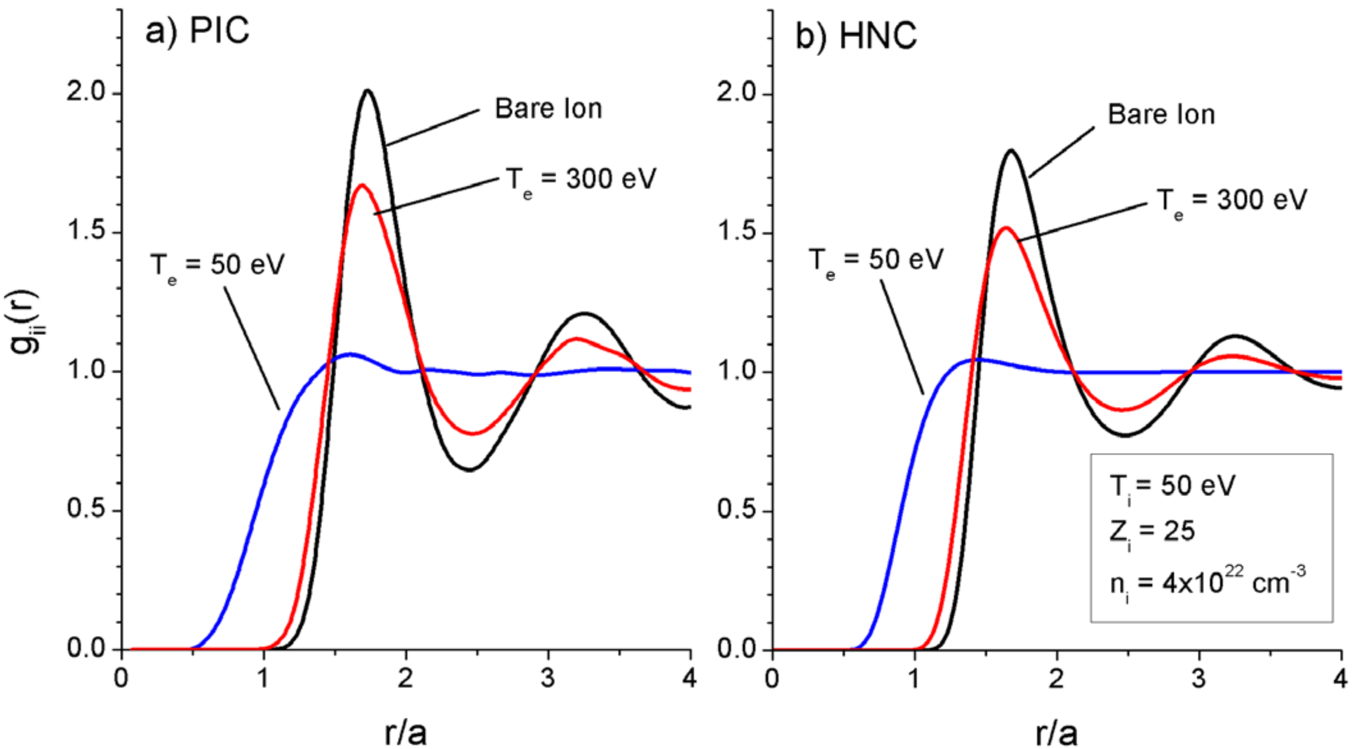
$Z_i = 25$
$m_i = 56m_p$
$n_e=10^{24}$ $cm^{-3}$
$T=T_i = T_e$

Wigner-Seitz radius:
$a = (3/4\pi n_i)^{1/3}$

Coupling Parameter:
$\Gamma=Z^2e^2/akT$

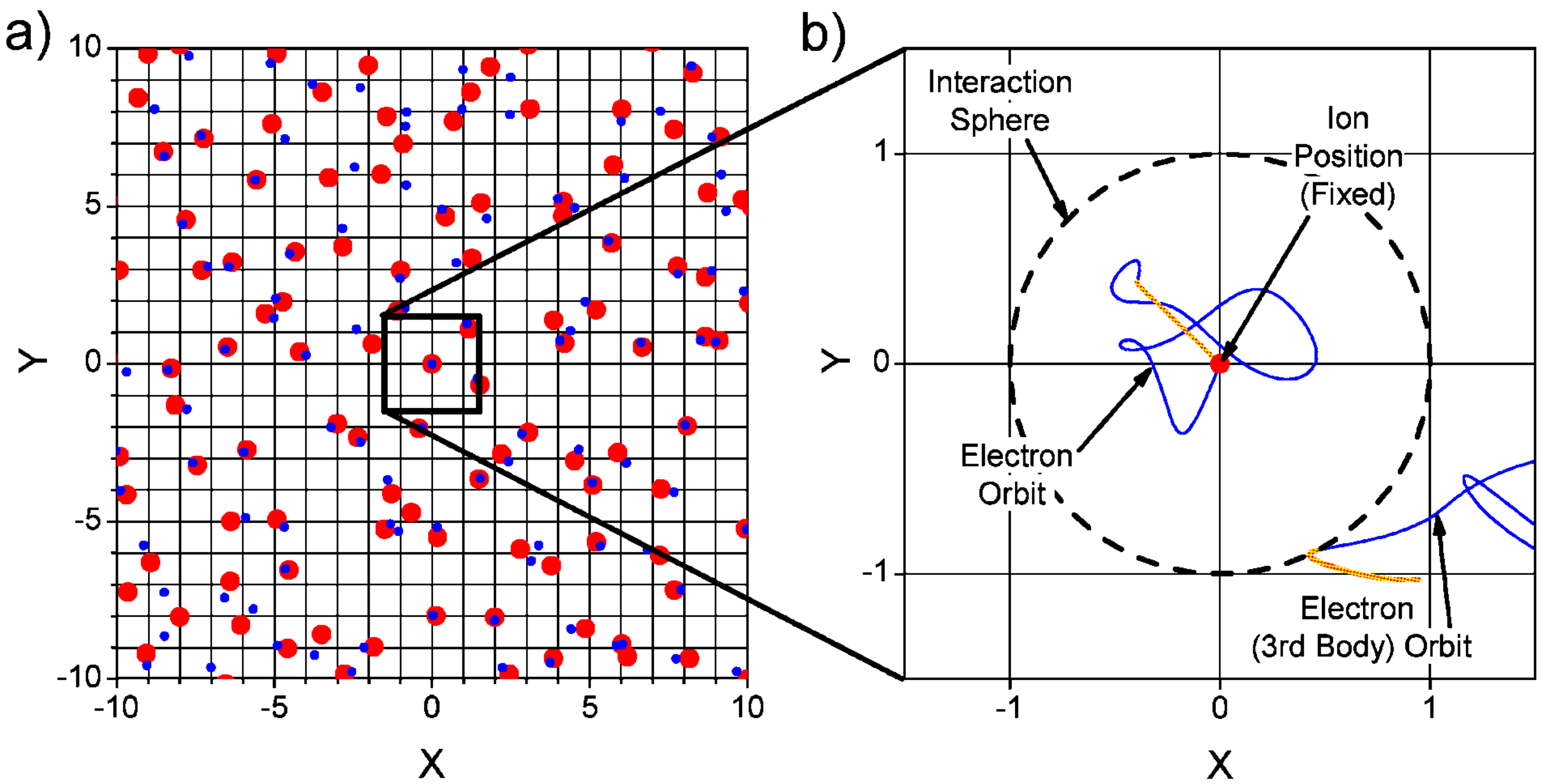
***Plasma typically defined by kinetic energy > ionization energy***
***Strongly coupled plasma occurs when PE > KE***

**Voss Sci/OSU**




***BRI with T. Curcic + STTR Transition***

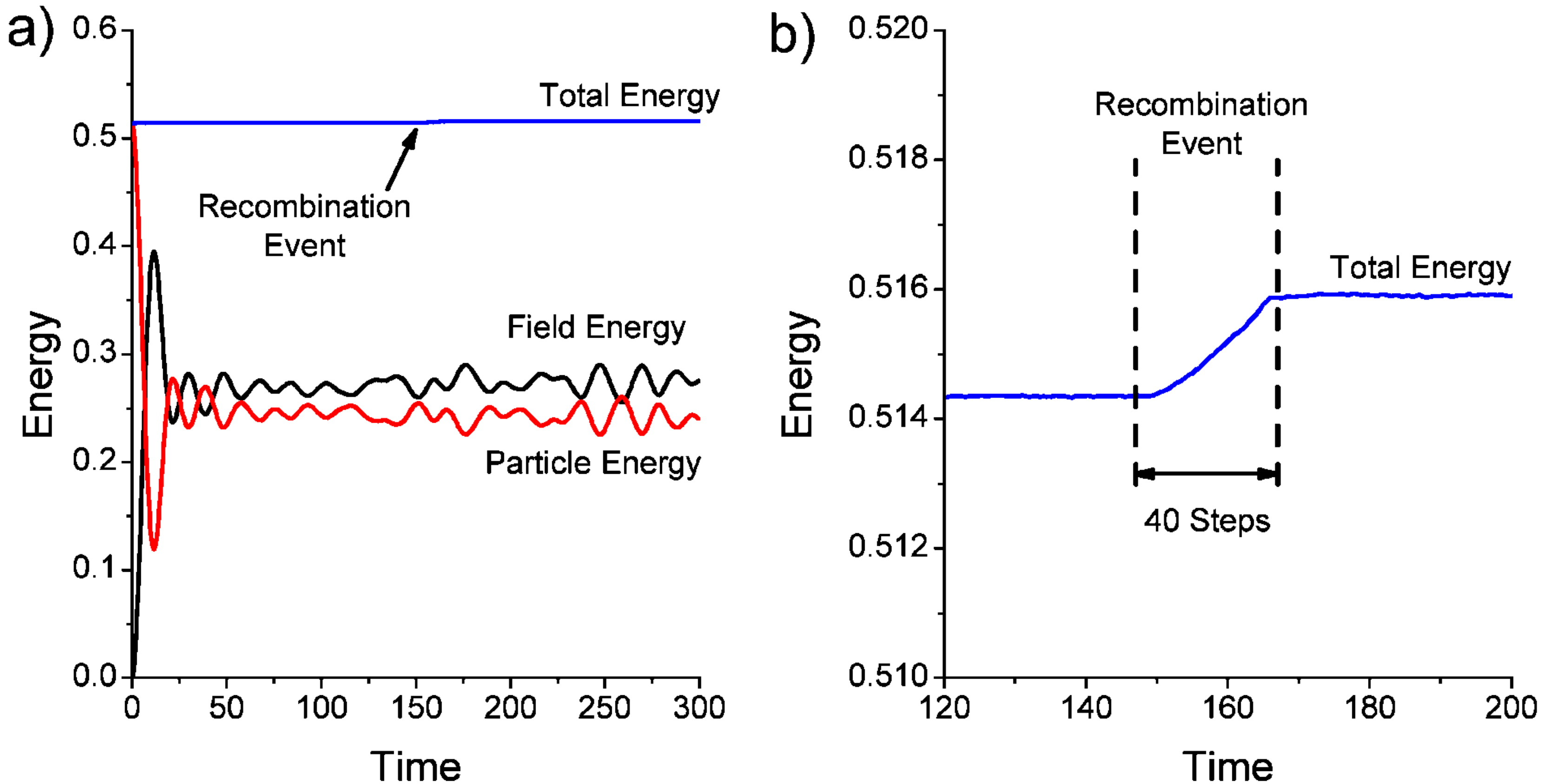
# Sample PIC simulation using the density decomposition scheme including a non-local three-body recombination event.




**Voss Sci/OSU**

## Atomic processes in PIC

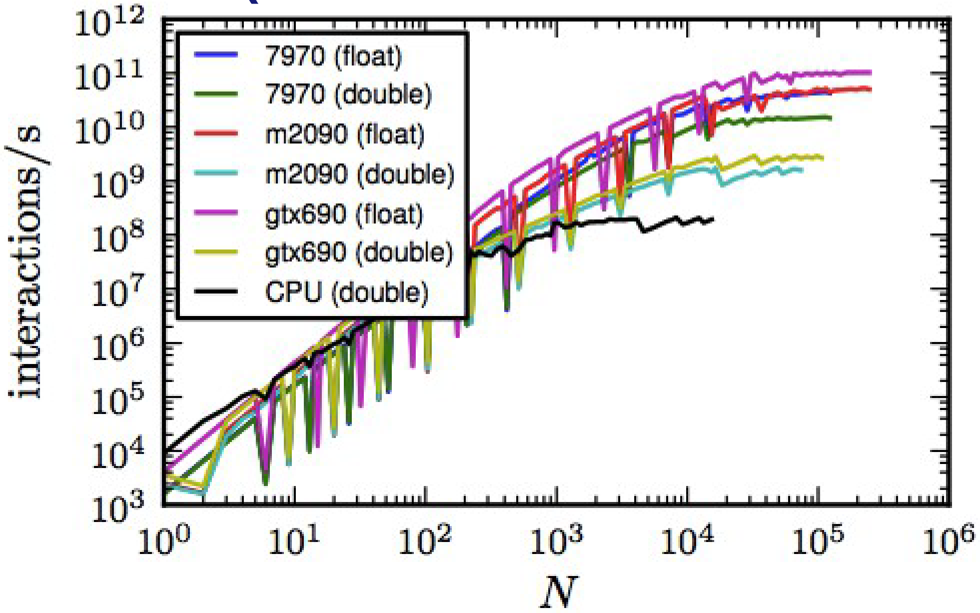
# Energy Evolution
# (40 time step duration)

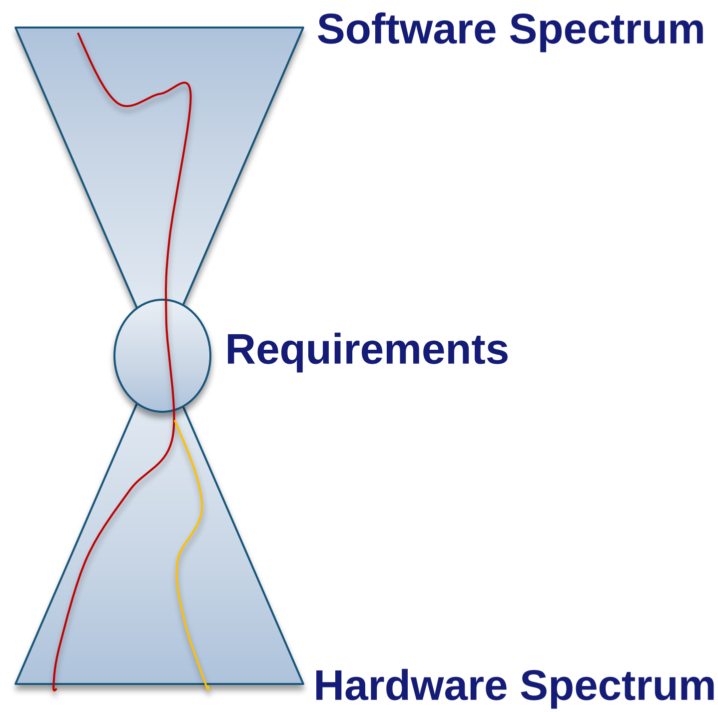



**Voss Sci/OSU**

# An Aside: Transformative Computation

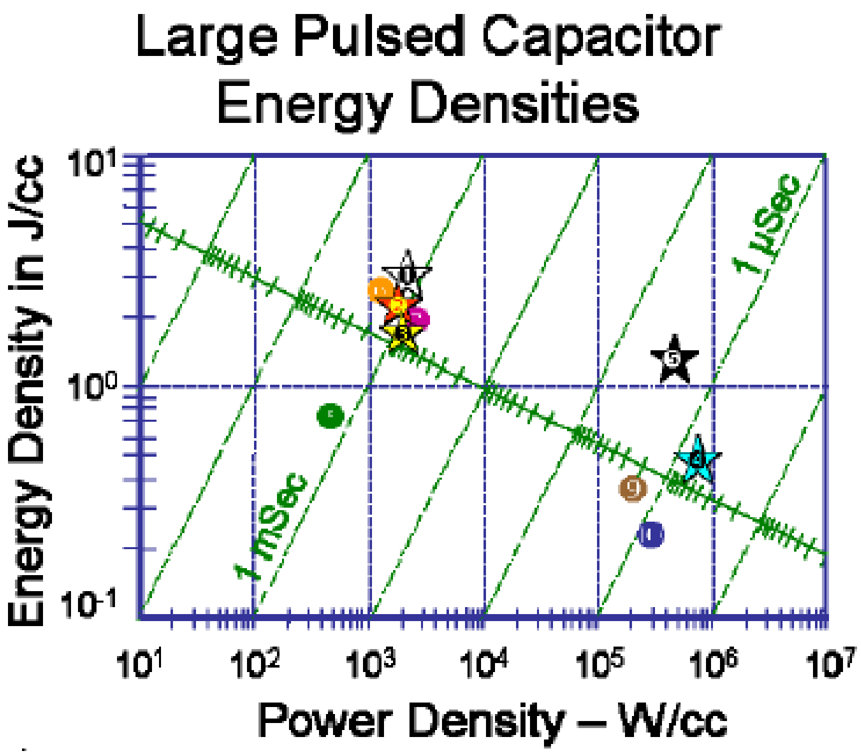
## *Tech-X (treecode for SCP on GPU)*

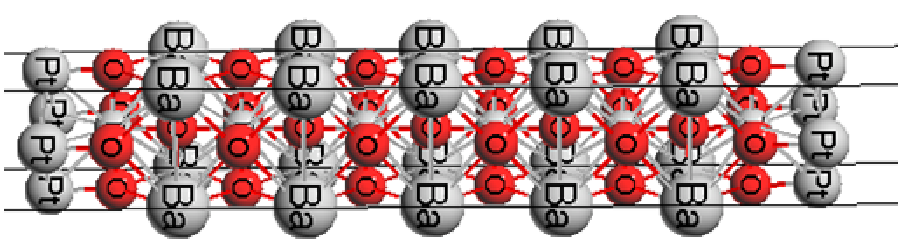



- **3 Recent Basic Research Initiatives (Curcic, Fahroo, JWL, Smith, Stargel)**
  - **Ultra-Scale and Fault-Resilient Algorithms: Mathematical Algorithms for Ultra-Parallel Computing**
  - **Transformational Computing via Co-Design of High-Performance Algorithms and Hardware**
  - **Transformational Computing in Aerospace Science and Engineering (Q. Algorithms for Physics)**

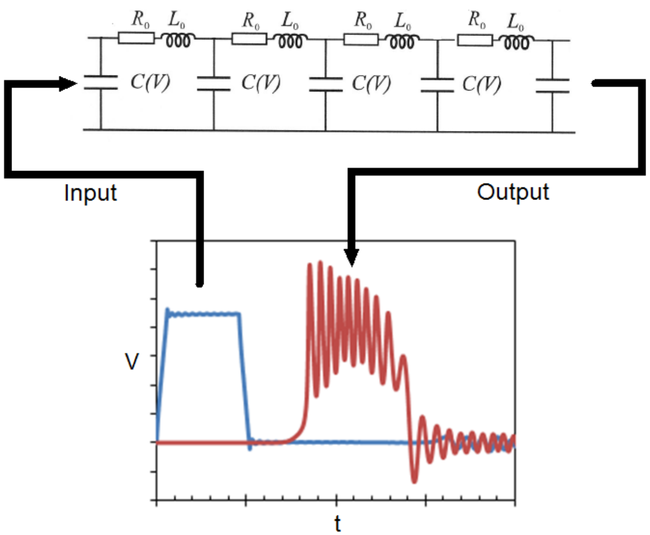
# Pulsed Power Science Challenges

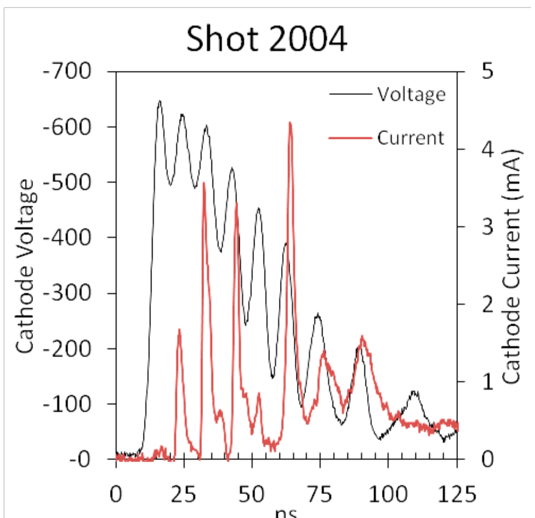


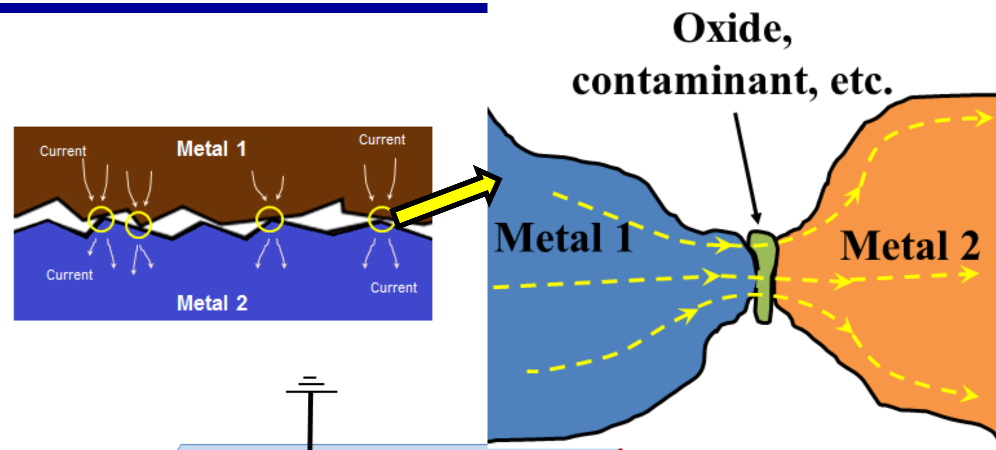



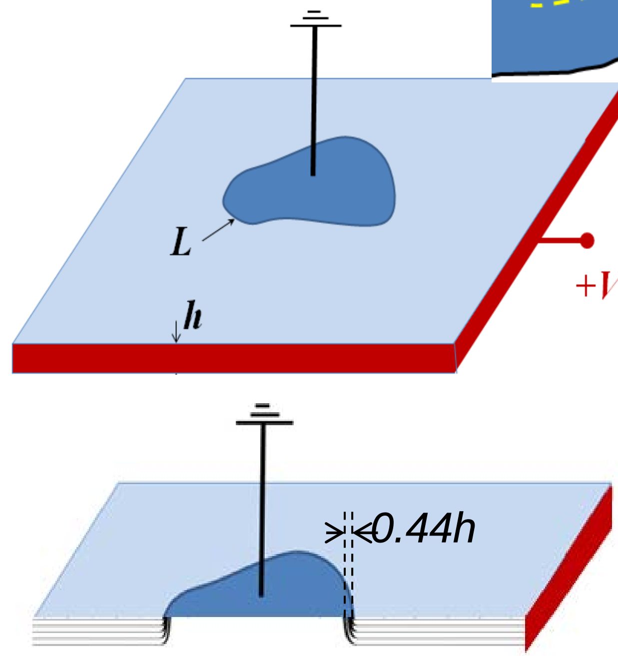

- Fundamental focus on transport of charge and energy through solid-state high-energy materials
- MURI on Magnetic-Energy Conversion with Sayir
- BRI on Metal-Dielectric Interfaces with Sayir
- Engineer materials to provide competing characteristics of
  - Energy density (ε)
  - Rapid discharge capability
  - Breakdown Dielectric strength (E)

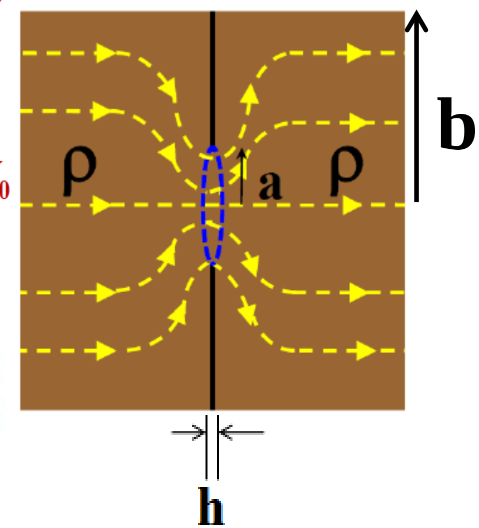
# Pulsed Power Successes



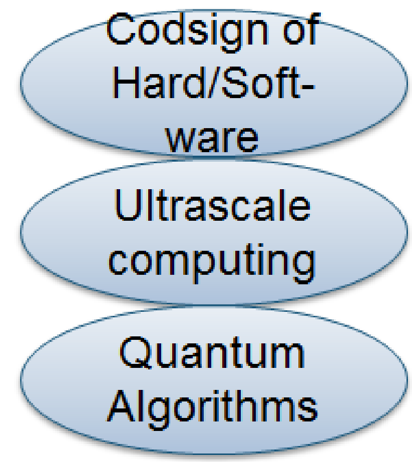



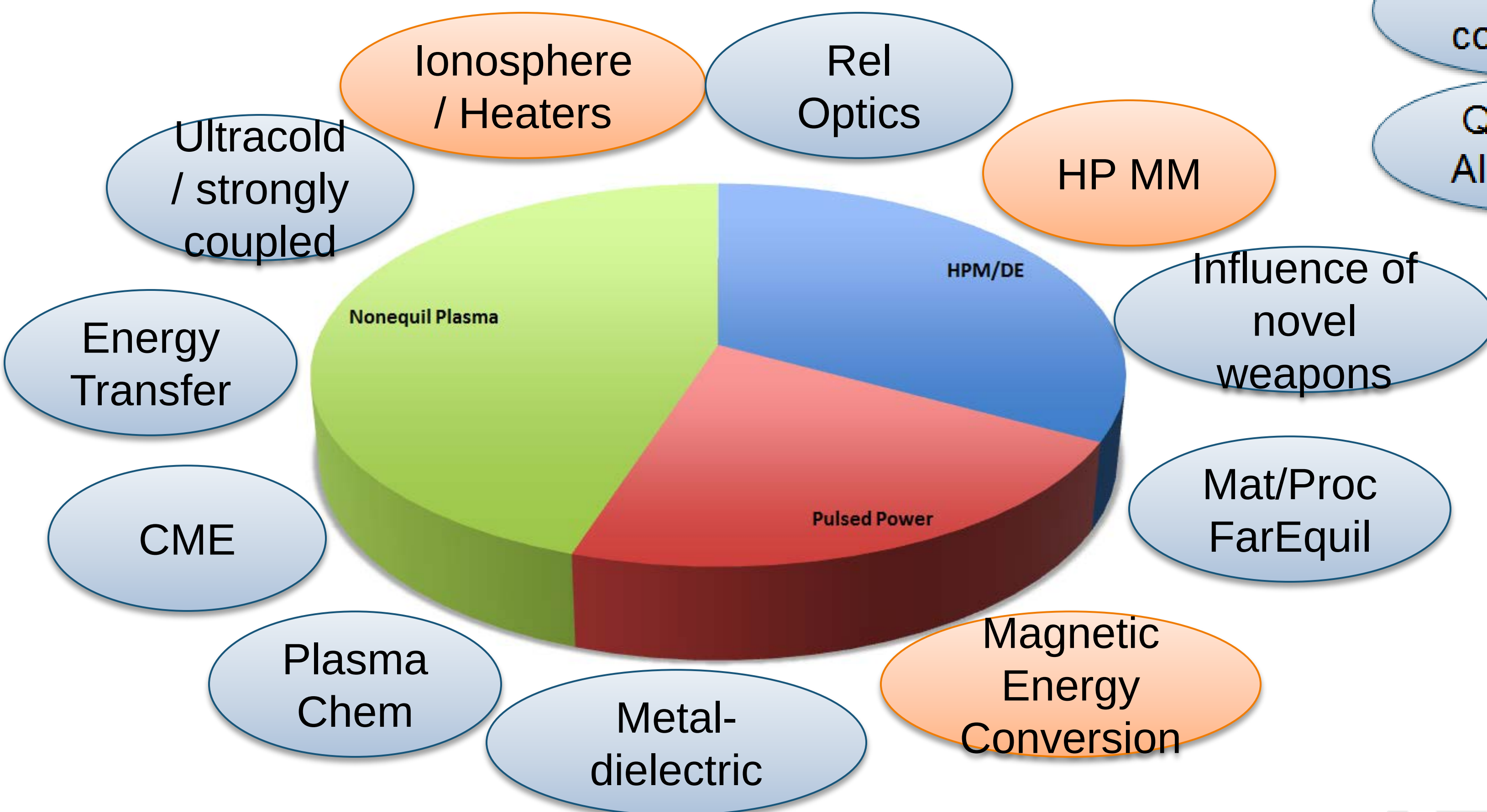




***S. Heidger, STAR team      Zhang, UM***

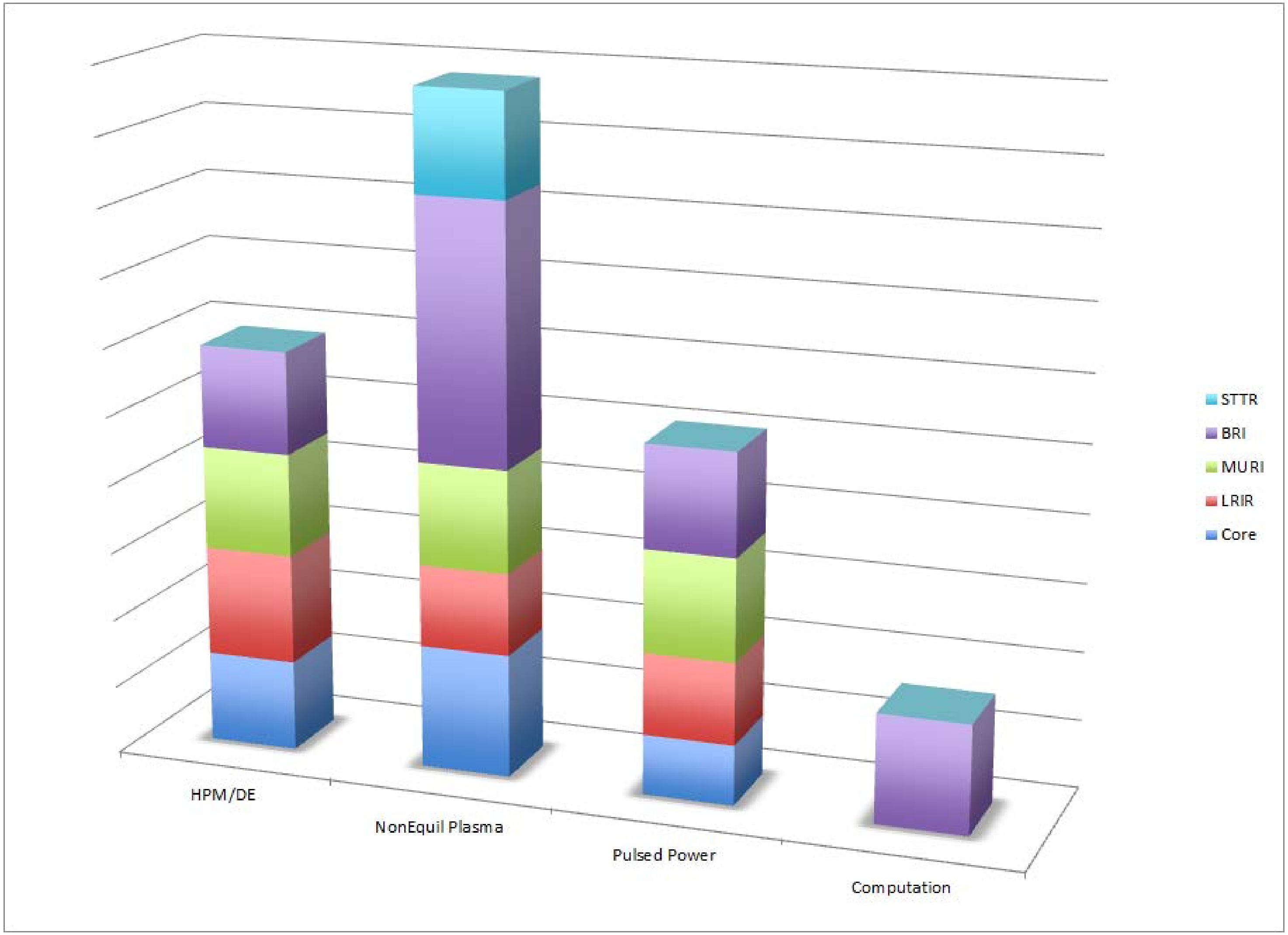
# New Initiatives and Resources

## *Collaborations across AFOSR*



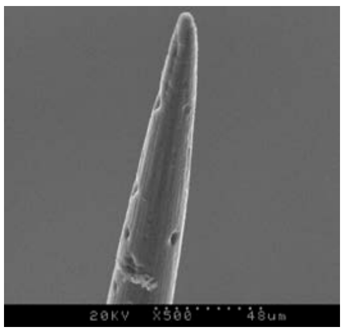



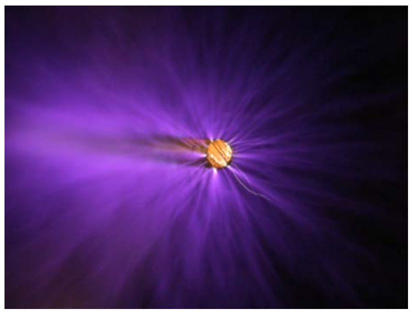
# Resources

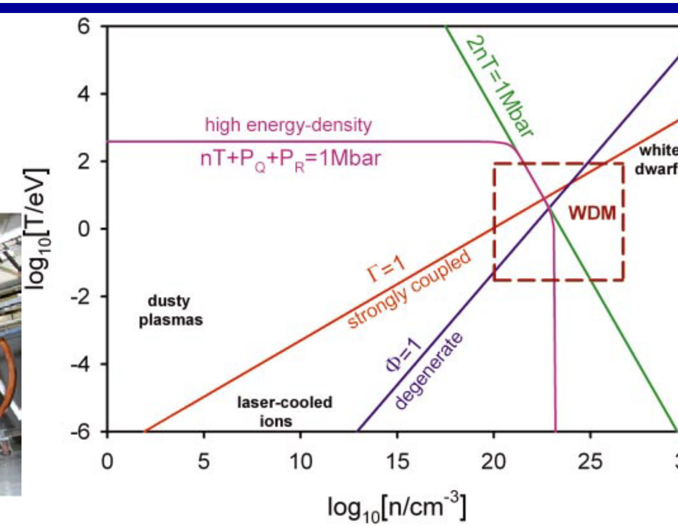


STTR
BRI
MURI
LRIR
Core
HPM/DE
NonEquil Plasma
Pulsed Power
Computation

# AFOSR is the leading DOD 6.1 organization for non-equilibrium plasma physics, especially for HPM/vacuum electronics EM sources






**fs to hrs; nm to 100s km; solid-state energy/charge transport to plasma to WDM**

## Collaborators/Teammates

- **Active collaborations with AFRL, ONR, ARL, DTRA, DARPA, NSF, DOE, and Air U**
- **Joint project with DARPA in micro-plasmas**
- **Close interactions with 9 LRIR, 3 MURI, and 11 BRI (fundamental sciences finds a wide range of collaborations)**